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On the question of solar flare site in the active region

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Abstract : The site of the solar flares in the active region has been estimated in a statistical way. The correlation coefficient between the integrated flare intensity in H_α and the peak flux of the associated radio burst has been found out for various observed frequencies of radio emission. The aforesaid coefficient is found to peak around 2–4 GHz at which the flare-burst association is found to be maximum, giving rise to the fact that most of the H_α flare onset takes place in the region of 2–4 GHz radio emission.

Keywords : SUN, flare site

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The question of primary site of flares in the solar atmosphere has been treated as one of the unresolved issues like the flare energy source, the energy release mechanism, the type of instability during flare build-up, the topology of the energy-release region as well as the triggering process. During Solar Maximum Mission in 1981, several attempts [1] were made in order to exploit the experimental techniques for *in situ* observations of the primary site of the solar flares in the active region. Till now, no satisfactory results have emerged out. In the present paper, an attempt has been made for getting an insight into the same problem by undertaking a study on the solar radio bursts in a wide frequency band ranging from 0.245 to 35 GHz in relation to the integrated intensity as well as the burst-productivity of H_α flares.

The data required for this purpose have been collected from the Solar Geophysical Data bulletins published by the U.S. Department of Commerce covering the period from 1981 to 1989 and are displayed in the Table 1.

In order to avoid the error in the given flux densities due to the use of different time constants of receivers, to the differences or deficiencies of the calibrating systems, only the single station data have been taken into consideration for all the frequencies except 35 GHz.

But as the burst data at 35 GHz is meagre in number, the experimental data of three stations have been included in order to make it statistically sound. The *H*-alpha flares have been

Table 1. Radio burst data from various stations.

Frequency of observation (GHz)	Number of radio bursts	Station / Latitude
0.245	708	LEAR 22S
0.410	666	LEAR 22S
0.650	697	GORKY 56N
0.950	680	GORKY 56N
2.800	391	OTTA 45N
4.995	196	SGMR 42N
8.800	215	SGMR 42N
11.800	292	BERN 47N
15.000	724	KISV 43N
17.000	329	NOBE 36N
19.600	179	BERN 47N
		BERN 47N
35.000	188	NAGO 35N
		NOBE 36N

associated with the radio bursts on the basis of the following criteria : (i) if the times of maxima of both the radio bursts and the correlated flares coincide exactly with each other : (ii) if the life time of the burst falls within the span of the total duration of the related H_α flares. But as far as the starting times of both the radio bursts and the respective flares are concerned, the following Table 2 gives an idea about the percentage of bursts at various frequencies whose starting times are within ± 5 min of that of the associated flares.

It appears from the above table that the starting times of radio bursts fall within ± 5 min of that of the associated flares in more than 50% cases in all the frequencies. Moreover, in more than 95% cases the durations of the associated flares have values greater than 5 min.

For studying the association of flares with the radio bursts, only the H_α flares which have several eruptive centres (F-type according to the IAU system of notation classified on

Table 2. Selection criteria of radio bursts and associated flares.

Frequency of observation (GHz)	Number of cases with starting times < 5 min (in %)	Percentage of flares with duration > 5 min
0.245	50.6	96.4
0.410	53.4	94.6
0.650	53 8	93 5
0.950	58.8	95.1
2.800	55.3	97.8
4.995	59 3	98 2
8.800	59 1	98.2
11.800	63.2	97.2
15 000	66.4	94.7
17.000	54.4	97 5
19 600	61.0	99 3
35.000	54 9	99.1

the basis of their visual features) have been taken into consideration, because of the fact that they have higher values of integrated intensity as well as greater impulsiveness [2,3] compared to other types of H_α flares.

The integrated intensity $I_{(i)}$ of each of the H_α-flares was derived by using the following formula [4] :

$$I_{(i)} = 7.6\, A_s^2,$$

where A_s is the flare area measured in square degrees.

After calculating the integrated intensity of each of the burst-associated H_α-flares, the correlation coefficient between the peak fluxes of radio bursts and corresponding integrated intensity of the associated H_α-flares has been found out for the population of radio bursts observed at a particular frequency. This has been repeated for the other frequencies as well and the results thus obtained are shown in Figure 1. The correlation coefficient increases with the increase of frequency and peaks around 3 GHz after which it decreases with the increase of frequency. The burst-flare association at different frequencies has been displayed in Figure 2 which shows that the association increases with the increase of observing frequency.

In the next phase, altogether 250 H_α-flares having several eruptive centres as their visual indications have been collected from the S. G. D. bulletins. Each of these flares has been associated with the respective radio burst and the number of occurrences of radio bursts has been found out in each frequency separately. The flare-burst association thus obtained has been shown in the same Figure 1. The said association also peaks around 2.5–3 GHz frequency, below and above of which the association falls off.

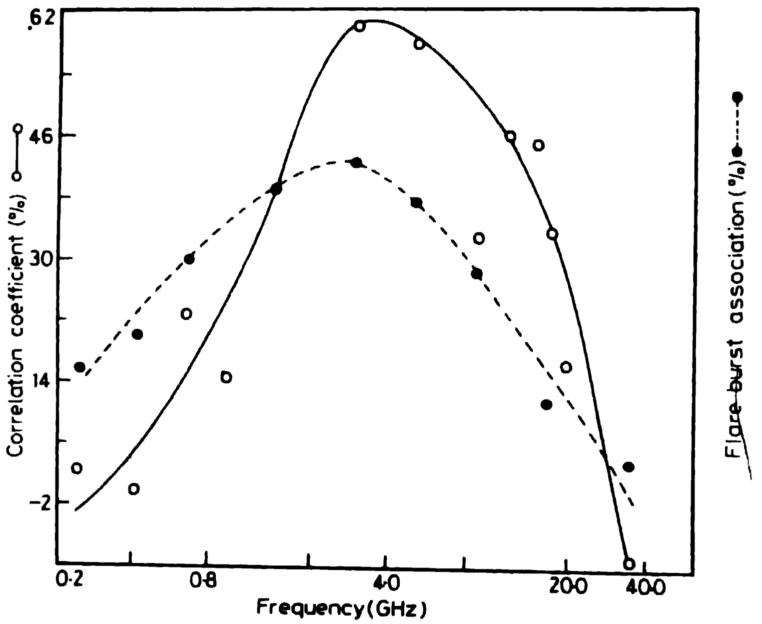

Figure 1. The solid line curve shows the frequency dependence of the correlation coefficient between the integrated intensity of flares and peak fluxes of radio bursts. The dotted line curve gives the variation of flare-burst association with the frequency of radio bursts

The maximum correlation coefficient between the flare intensity and the associated burst peak intensity has been obtained for the burst frequency range 2.1 to 6.7 GHz which corresponds to the 90% and above of the maximum value of the correlation coefficient. Similarly, for the flare-burst association, the frequency range is 1.4 to 4.2 GHz that corresponds to the 90% and above of the maximum value of the flare-burst association. Hence, the common frequency range is 2–4 GHz which holds good for both the flare-burst energy correlation as well as the flare-burst number association that indicates the measure of burst productivity of flares.

Just like flare index, comprehensive flare index [5], and flare importance sum [6], the integrated intensity gives an estimate of the energy output of a flare. Above 60% correlation between the peak fluxes of radio bursts and the corresponding values of integrated intensity of H_α-flares, clearly points to the fact that the energetics of these two phenomena in the solar atmosphere have one to one correspondence in the frequency range 2–4 GHz of radio emission. Moreover, in considering the burst-productivity of flares, only those H_α-flares which have large number of eruptive centres *i.e.* containing large number of instabilities, have been taken into account. The burst-productivity has also been found to be maximum in the same frequency range 2–4 GHz. But so far as the number of occurrences is concerned, the number of flares increases with the increase of frequency of radio bursts as evident from Figure 2.

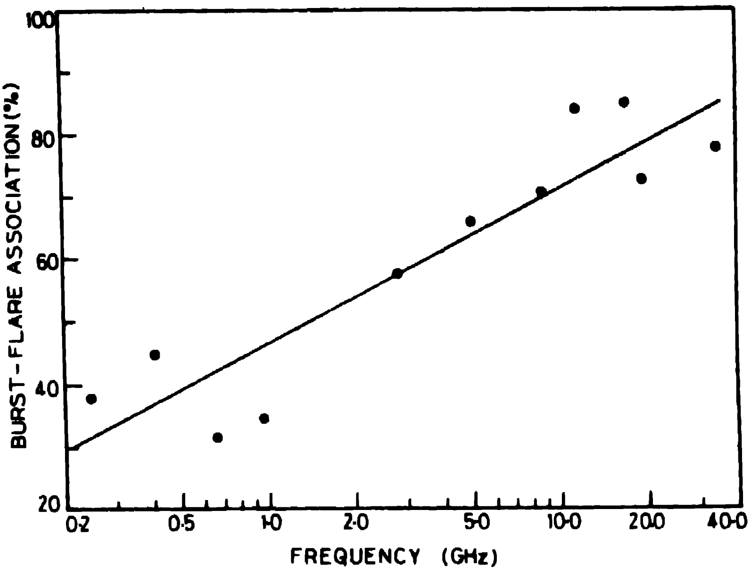

Figure 2. The variation of burst-flare association with the observing frequency of radio bursts

Hence, the probable site of most of the flares may be presumed to be located in the region from where the 2–4 GHz radio bursts originate. This frequency range does not coincide with the frequency at which the spectral peak of the microwave radio emission occurs, which is around 9 GHz as it appears from the spectral study by the various authors from time to time [7–9].

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